Bently's Corner

Perturbation testing:
Determining the instability safety margin of a new machine

By Donald E. Bently,
President and Chairman

Mechanical run tests and full-load testing are recommended by the American Petroleum Institute when commissioning a new machine. These tests provide valuable synchronous rotative speed data for determining the residual bow and balance condition of a new machine. But they don't provide nonsynchronous frequency data for assessing the operating stability of a new machine.

Knowing a new machine's rotor stability characteristics under operating conditions enables you to establish the safety margin for that machine. This type of information is obtained through nonsynchronous frequency data.

Nonsynchronous frequency vibration is defined as vibration of a different frequency than the rotative speed frequency. Synchronous means the rotative speed frequency.

A large group of malfunctions, generally known as the "forward circular whip" category, often adversely affect rotor performance. Included in this category is the well-known oil whirl mechanism, which creates forward circular whirl at the swirl rate of the oil in the bearing (usually about 43 percent of rotative speed).

The main malfunctions in this category include oil whip, steam whip, pumping whip, seal whip, internal friction whip, and aerodynamic cross coupling whip. All of these types of malfunctions drive the rotor into forward circular vibration at or near the first balance resonance of the machine, usually below rotative speed.

There have been no tests to examine the rotor system for its propensity, or non-propensity, to exhibit problems in the forward circular whip category.

Data on machine behavior at nonsynchronous speed can be obtained through perturbation testing to detect the conditions that stimulate these vibrational phenomena and give you some ability to analyze the safety margin of the machine from rotor instability.

What is perturbation testing?

The purpose of perturbation testing is to acquire nonrotative speed data during conditions that simulate the machine's actual operating state.

Perturbation testing involves applying an external force on the machine system and measuring the machine's response to this force during startup, shutdown, and normal running speed (see Figure 1).

Several types of perturbation devices can be used to apply the external force: a shaker device which introduces a unidirectional harmonic force on the machine (see Figure 2) or a motor-driven perturbation system, consisting of a electric motor, shaft, and perturbation mass, that is attached to the end of the new machine (see Figures 3 and 4).

The motor-driven perturbation system applies harmonic force on both the vertical and horizontal axes. Applying the external force on two axes more accurately simulates the actual operating state of a rotating machine. Under normal operating conditions, a machine usually vibrates in both axes perpendicular to the axis of rotation. ▶

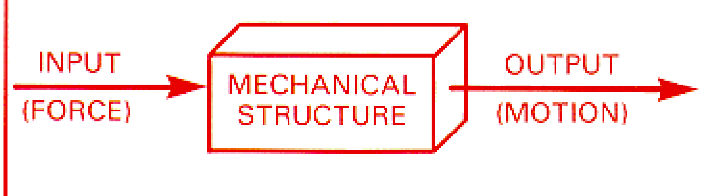


Figure 1

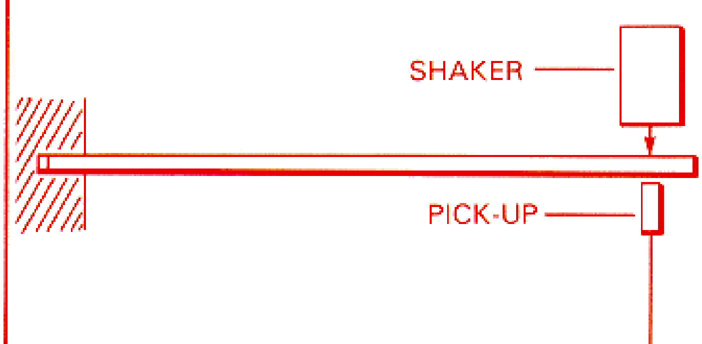


Figure 2

How perturbation testing works

The procedure for using these force generating devices for perturbation testing is as follows:

1. Operate the machine at normal speed range with load, alignment, bearing clearances, temperature, and other operating conditions as close to normal as possible.
2. Apply the perturbation force with a constant amplitude and frequency, ranging from 0 rpm to the desired speed range.
3. Record rotor response data throughout the speed range, using displacement probes and a Keyphasor™ that observes a one-per-turn timing mark on the shaft to make plots of the data.

Several types of perturbation are possible, including monoharmonic force, impulse, white noise, and square waves. They can be applied unidirectionally or in two directions.

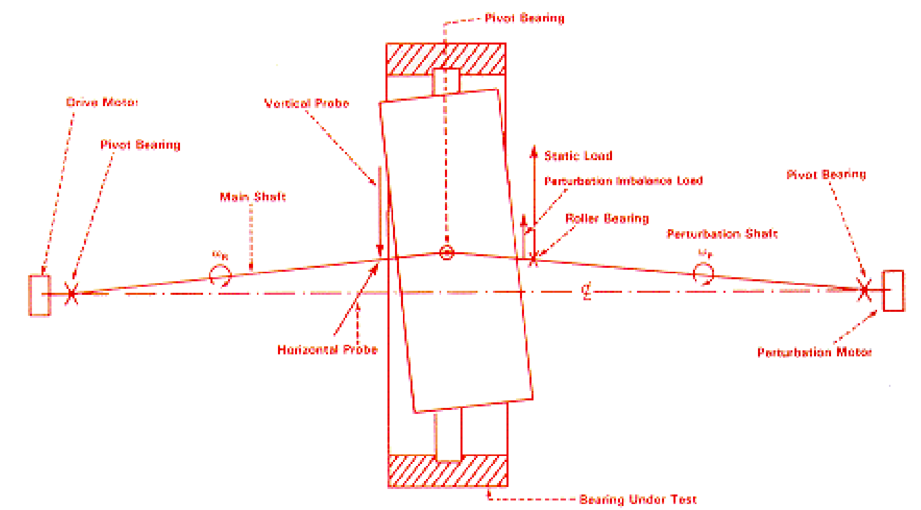


Diagram of Perturbation Test System

Figure 3

Because of the fundamental nature of rotating machines, the most appropriate type of perturbation for rotating machinery is regular, periodic harmonic force (Figure 5). For the most accurate results, the force should be applied vertically and horizontally to the rotor. This creates a rotating force. The direction of the rotating force may be the same as the rotation of the rotor (forward perturbation) or it may be in the opposite direction (reverse perturbation).

The rotor response is analyzed to determine the presence of rotor instability mechanisms and thus more accurately assess the machine's safety margin from rotor instability.

Computerized data acquisition and reduction systems, like Bently Nevada's ADRE II® (Automated Diagnostics for Rotating Equipment), are efficient tools for collecting, storing, and reducing this data.

Using perturbation tests as part of acceptance testing

Perturbation tests are commonly used in the laboratory for investigating and documenting the mechanical structure and behavior of rotating machinery. The use of perturbation testing in the field has the potential to vastly increase ▶

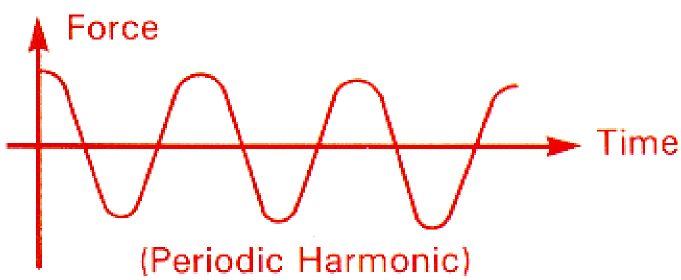


Figure 5

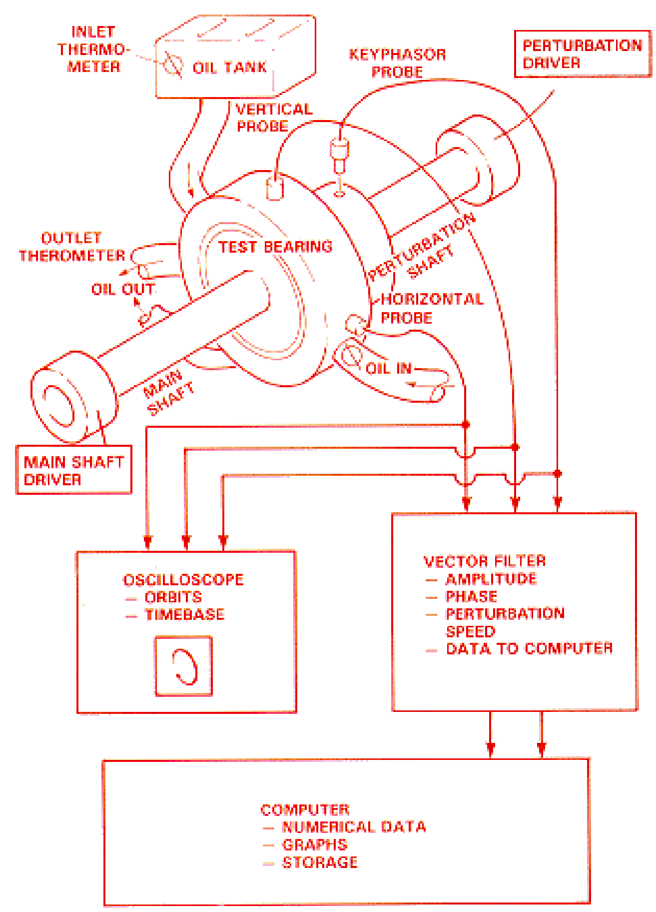


Figure 4

your knowledge of the dynamic behavior of machines under actual operating conditions.

Presently, laboratory studies compare a theoretical solution for a machinery behavior problem to the response of a scaled model during experiments that simulate the problem. Criteria for operating characteristics are established if the theoretical solution and the machine response to the experiment agree.

The actual machine behavior under normal operating conditions cannot be fully duplicated in the laboratory, however. Perturbation testing in the field will enable you to document the machine's response to known behavior under normal operating conditions. This will further enable you to calculate the operating characteristics of a machine and determine the safety margin of the machine to rotor instability mechanisms. These operating characteristics can be used, in addition to mechanical run and full-load testing, as criteria for the acceptance of a new machine.

The challenge

Present machine design usually does not permit the installation of perturbation systems on new machines. In the future, machines will have to be configured to allow access in the rotors for the placement of force generating devices and probes for the perturbation system.

This poses a challenge for machinery engineers: to determine ways to easily and economically implement perturbation systems on new machines.

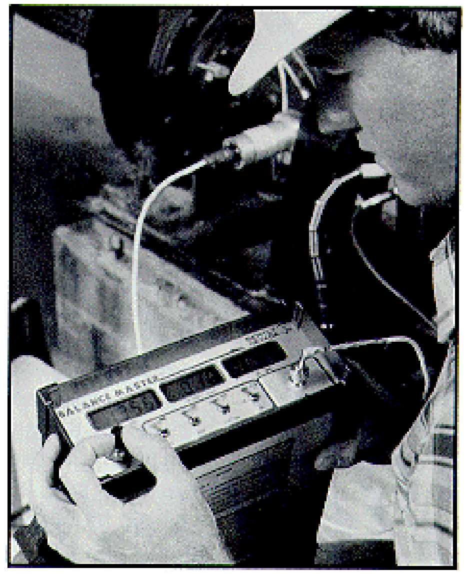
Bently Rotor Dynamics Research Corporation is studying methods for implementing perturbation systems in the field. We welcome any suggestions or research data on this topic.

We also extend the opportunity to share your knowledge on this subject at our Senior Mechanical Engineering Seminar in Carson City, Nevada, June 11-15.

The ability to more accurately assess the operating stability of a new machine and to establish safety margins for the machine will benefit us all in improved machine reliability. Perturbation testing under normal operating conditions makes this possible. ■

New Products

On-site balancing with the Balance Master™



Many small rotating machines can be balanced or trim-balanced on site with better results than sending them to a separate balancing facility. Bently Nevada's Balance Master™, a portable balancing instrument, provides maintenance technicians and engineers with the information needed to quickly and accurately balance machinery on site.

Properly balanced machines result in improved operation of rotating equipment and reduced machine shutdowns caused by balance problems. The Balance Master can be used for on-line balancing as part of a plant-wide predictive maintenance program for small motors, fans, pumps, compressors, and other rotating machinery used in industrial plants.

The Balance Master processes information on gap voltage, speed, overall vibration amplitude, and 1X rotative speed amplitude and phase. This information appears on the device's LCD displays.

The information can be plotted on the polar graph located on top of the Balance Master or can be input into a hand-held computer. Bently Nevada offers a balance correction software program for the Hewlett-Packard 41CV hand-held computer.

This program determines the amount and location of the required correction weights. It also provides predicted unbalance response and machine trim balancing information.

The Balance Master's portability and low cost makes it ideal for use on non-critical rotating machinery. It also can be used to balance critical and essential machinery with up to four balancing planes, using the HP 41CV balance correction software program.

The Balance Master is battery operated and easy to operate. It requires little operator training to solve basic balance problems.

The Balance Master accepts inputs from a wide variety of transducers through easily-changeable transducer input modules. To operate, the user simply plugs in the appropriate transducer input modules and connects the transducers to the device. After setting the Filter and Mode switches, the data reading is taken.

For more information, please check the following L numbers on the return card:

Balance Master data sheet, L0547.

HP 41CV Machinery Balancing Software data sheet, L0560.